EE359 – Lecture 17 Outline

- **Announcements:**
  - new HW posted, due Friday
  - End-of-Quarter schedule and possible bonus lecture
    - No lecture March 5
    - Advanced topics lecture ; will extend last class March 12 (1-2:50 or 1:30-3:30)
    - Final exam: Tues March 17, 3:30-6:30pm, here. More details soon.
- FFT implementation of MCM (OFDM)
- Implementation Challenges in OFDM
- Fading across Subcarriers
- MIMO-OFDM

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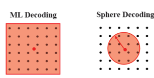
Review of Last Lecture

- MIMO RX Design (see supplemental handout):
  - Optimal Receiver is ML: finds input symbol most likely to have resulted in received vector, exponentially complex in M_t
  - Linear Receivers: First performs linear equalization: $\tilde{x} = Ay$ then quantizes $\tilde{x}$ to nearest constellation point $x \in \mathcal{X}^{M_t}$
    - Zero-Forcing ($A = \mathbf{H}^{\dagger}$, the Moore-Penrose pseudo inverse of H): (if H invertible, equals inverse, else $\mathbf{H}^{\dagger} = (\mathbf{H}^H\mathbf{H})^{-1}\mathbf{H}^H$); forces off-diagonal terms to zero ($\tilde{x}_i = x_i + \tilde{n}_i$; $\tilde{n} = \mathbf{H}^{\dagger}n$, enhances noise)
    - Minimum Mean Square Error ($A = \mathbf{H}^H(\mathbf{H}\mathbf{H}^H + \lambda \mathbf{I})^{-1}$): $\lambda \propto 1/SNR$ Balances zero forcing against noise enhancement
- Sphere Decoder: Uses QR decomposition of H
  - Considers possibilities within sphere of transformed received symbol.
    - If minimum distance symbol is within sphere, optimal, otherwise null is returned

$\hat{x} = \arg\min |y - Hx|^2$ $Hx+n$



$\hat{x} = \arg\min_{x:|Q^H y - Rx| < r} |Q^H y - Rx|^2$ $Q^H y = Rx + Q^H n$

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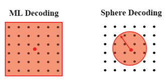
How does this reduce search complexity?

$\hat{x} = \arg\min |y - Hx|^2$

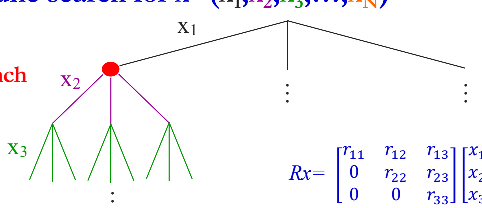


$\hat{x} = \arg\min_{x:|Q^H y - Rx| < r} |Q^H y - Rx|^2$

Need to compute $|Q^h y - Rx|$ $\forall x \in X^{M_t}$ to see if less than r

- Use tree search and upper triangular properties of R to prune search for $x = (x_1, x_2, x_3, \ldots, x_N)$

If $|Q^h y - r_{11} x_1| > r$, prune entire branch



$$Rx = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ 0 & r_{22} & r_{23} \\ 0 & 0 & r_{33} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix}$$

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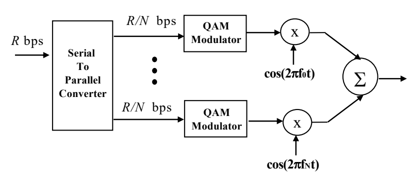
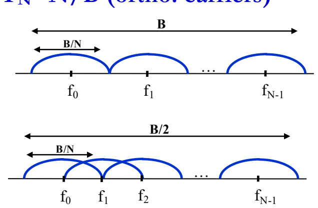
Review Continued

- ISI Mitigation: Can mitigate ISI with equalization (not covered), multicarrier modulation, or spread spectrum
- Multicarrier Modulation: breaks data into N substreams ($B/N < B_c$); Substreams modulated onto separate carriers
  - Substream passband BW is B/N for B total BW
  - $B/N < B_c$ implies flat fading on each subcarrier (no ISI)
  - Can overlap channels for $f_i - f_{i+1} = T_N = N/B$ (ortho. carriers)





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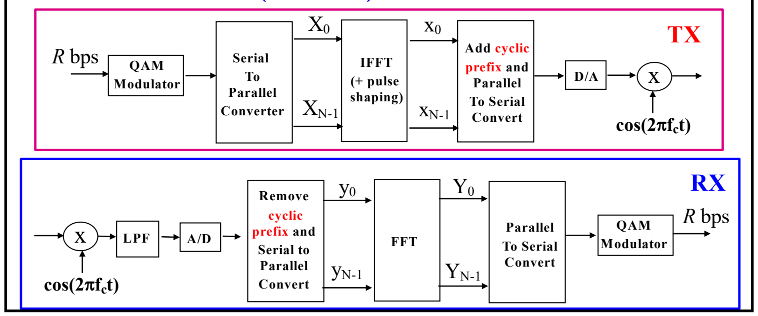
FFT Implementation of MCM (OFDM)

- Use IFFT at TX to modulate symbols on each subcarrier
- Cyclic prefix makes linear convolution of channel circular, so no interference between FFT blocks in RX processing
- Reverse structure (with FFT) at receiver



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OFDM Design Issues

- Timing/frequency offset:
  - Impacts subcarrier orthogonality; self-interference
- Peak-to-Average Power Ratio (PAPR)
  - Adding subcarrier signals creates large signal peaks
  - Solve with clipping or PAPR-optimized coding
- Different fading across subcarriers
  - Mitigate by precoding (fading inversion), adaptive modulation over frequency, and coding across subcarriers
- MIMO-OFDM
  - Apply OFDM across each spatial dimension
  - Can adapt across space, time, and frequency
  - MIMO-OFDM represented by a matrix, extends matrix representation of OFDM alone (considered in HW)

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Main Points

- MCM implemented with IFFTs/FFT (OFDM)
  - Block size depends on data rate relative to delay spread
- OFDM challenges: timing/frequency offset, PAPR
- Subcarrier fading degrades OFDM performance
  - Compensate through precoding (channel inversion), coding across subcarriers, or adaptation
- OFDM naturally combined with MIMO
  - Orthogonal in space/freq; extended matrix representation
  - 4G Cellular and 802.11n/ac/ax all use OFDM+MIMO

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